From LCA to PSS – Making leaps towards sustainability by applying product/service-system thinking in product development

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Abstract

Life Cycle Assessment (LCA) is the standardised and globally recognised tool for quantifying environmental impact of goods and services. A key aspect in LCA is the consideration of whole life cycle systems.

The application of LCA in product development inherently comprises the quest for optimisations on all system levels. However, as the act of ecodesign conventionally focuses on physical products, the search for potential optimisations is usually directed ‘downwards’, i.e. towards lower system levels, resulting in *optimised components within products* rather than *optimised products within their surrounding systems*.

This paper will exemplify that when broadening the ecodesign horizon to environmental product/service-system (PSS) design, there is a better possibility of applying a system-oriented life cycle thinking approach, and therefore a potential to yield extreme improvements towards sustainability.

Keywords

Life Cycle Assessment (LCA), Product/Service-System (PSS), system-oriented thinking, ecodesign, product development

1 INTRODUCTION

Since the Brundtland Commission’s introduction of the concept of sustainable development in the late 1980’s many ideas and concrete tools have been suggested to support the implementation of sustainability in its three dimensions: economy, ethics and environment. Integrating elements in these three dimensions are supply-and-consumption patterns, where ‘products’ and thus development of future products play a central role. Despite the existing instruments within each dimension, examples of approaches that treat the implementation task in an integrated way - i.e. the three dimensions at the same time - are rare.

In this paper we sketch the potentials lying in the concept of Product/Service-Systems (PSS) to reach such an integrated approach. As a key tool in the environmental dimension, we describe Life Cycle Assessment (LCA) and show that although LCA applied in product development often leads to sub-optimisations this is not due to a lack in methodology but rather due to lack of system-thinking when applying LCA. In fact, LCA methodology covers all necessary elements for its application within PSS. Challenging the conventional artefact-fixated approach an important concept behind the PSS approach is to transform business from being based on the sale of goods to business based on offering a combined product/service-system that continuously provides value to the customer.

Furthermore, we describe current activities at the Technical University of Denmark that aim at a better understanding and development of the PSS concept including its application in industrial projects.

2 LIFE CYCLE ASSESSMENT AND SYSTEM ASPECTS

The object of an LCA is always a ‘Functional Unit’ - a quantitative and qualitative description of the performance of the ‘product system’, i.e. of the product or service to be assessed with its related processes taking place in the life cycle stages comprised in the LCA. This performance description is used as a reference unit in the LCA, for instance when quantifying environmental impact of the product system or when comparing different options [1, 2].

2.1 LCA covers both services and physical products

A Functional Unit in an LCA of an office chair may for instance be formulated as “*Provision of comfortable office seating for an average person for 8 hours a day, 5 days a week over 15 years*” [3]. Notice, that such a Functional Unit can be delivered by a physical product or a service or a combination of both. It can, for example, refer to one office chair used during the entire specified 15 years or to a combination of two or more chairs with shorter use periods. Also, the chair or chairs can certainly be bought, rented, or borrowed and can be manufactured from primary materials, recycled materials, new components and/or refurbished components including continual component upgrading, and so forth. When comparing such options by means of LCA the only criterion is the fulfilment of the same Functional Unit. This flexibility of LCA makes it an equally powerful tool for assessing physical products, non-physical services and combinations of both.

2.2 LCA requires thinking in systems

As the focus in LCA on Functional Units indicates, a key requirement for any LCA practitioner is the need to think in systems: Not just the assessed (usually physical) product as such is in focus but rather the performance of the product in its surrounding system, usually over a whole life cycle and always within well-defined system boundaries.

Regarding this system aspect, it is important to notice that optimisations are generally more effective, the higher up on a system level they are applied. For instance, the potential for overall emission reductions increases dramatically when advancing from the optimisation of a conventional *car engine* to the optimisation of the *entire car* and further to the optimisation of *personal transportation* as a whole. Other examples include ventilators, light armatures and pumps. With each of these products it is by far more effective to optimise their operation within the system that they are part of (e.g. the whole ventilation system) rather than to improve the single product. Obviously, when optimising the environmental performance of whole systems instead of single elements, substantially higher improvements regarding environmental sustainability can be reached.

This key advantage of thinking in systems is required and promoted by LCA.

2.3 Avoidance of sub-optimisations and rebound effects

Optimising on higher system levels also makes unwanted sub-optimisations and rebound effects obvious and thus more likely to be avoided:

A sub-optimisation would occur if a component, e.g. a valve (Figure 1) in a cooling or air conditioning system, were to be improved in an isolated manner (e.g. by selecting other materials or other manufacturing technologies) rather than that the functioning of the valve within the cooling system (Figure 2) would be improved, e.g. by improving the valve's precision in terms of timing and released amount of coolant during a life time of, for example, 10 years [4].

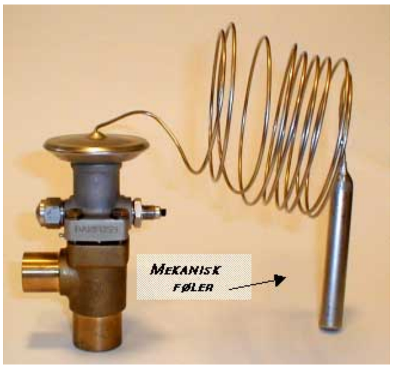

Figure 1: A valve in a cooling system (incl. a mechanical sensor) [4]. Single-product-oriented optimisation potentials for the valve lie e.g. in selecting different materials.

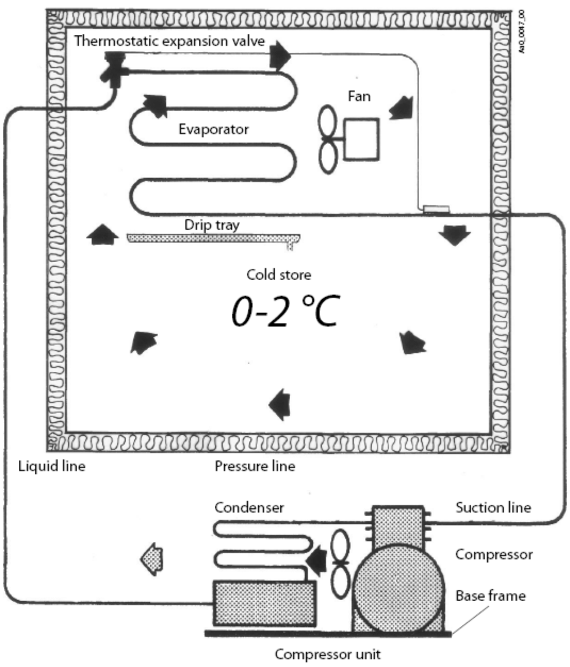

Figure 2: A sketch of the whole cooling system [5] with indicated position of the valve. System-oriented optimisation potentials for the valve lie e.g. in consumption of less electricity and coolant during a life time of e.g. 10 years.

This means, that components or other objects that are to be improved should always also be seen and optimised bearing in mind the system they are part of, in order to make use of often substantially higher improvement potentials than on a component level.

Another crucial issue that can be avoided when working on higher system levels are rebound effects. For instance, when reducing the potential environmental impact of a certain product by 50% (e.g. measured in CO_2-equivalents), it immediately becomes evident that selling more than twice as many units of this product would not reduce the overall environmental impact. Such a rebound effect can be avoided by matching market and sales expectation with improvement targets for existing products or services, respectively with development targets for new developments.

In both above-named cases the optimisation object could have been a physical product, a service or a combination of both, the latter of which being a very typical situation. This very strong relation between services and physical products as assessment object is captured by LCA and its methodological basis, making LCA an appropriate, capable tool to quantify environmental impact of product and/or service systems. Furthermore, LCA promotes the search for improvement potentials throughout entire life cycles and in this way sets the frame to encourage thinking in systems rather than in single-product solutions; all this while basing on a methodological framework that is fully in place. This ability to capture system aspects in LCA can be a strong advantage when applied during the development of products and/or services.

3 PRODUCT DEVELOPMENT AND ENVIRONMENTAL ISSUES

The activity of ecodesign in product development entails the quest for optimisations to be applied to a product in an attempt to minimise the overall environmental load caused. However, as the vast majority of ecodesign methods conventionally take their point of departure in discreet physical products, the search for potential optimisations is usually directed 'downwards', i.e. towards the components the product is made of, rather than "upwards". An example of this is the selection of a different engineering material or manufacturing process for a certain component rather than the redesign of the whole product – which could make the particular component obsolete – or the investigation of entirely different options of delivering the service of the product to be designed – which could make the entire product obsolete.

3.1 Upward- versus downward-oriented design

We find it useful to employ the theory of Olesen et al. [6] regarding 'environmental handles' to express our point with respect to upward- or downward-oriented design. In their theory, Olesen et al. present four main levels of systemic granularity of a product, in order of their optimisation potential. These four levels are:

- Technology (uppermost-oriented)
- Structure
- Sub-systems
- Components (downward-oriented).

Exemplifying the idea of upward-oriented redesign, Figure 3 depicts a conventional stapler and a stapler that works without staples.

While fulfilling a comparable functionality (definable in a Functional Unit) the two staplers employ two completely different working principles (on a technology level). One that may be called “attach clip” and another one that may be called “cut and fold paper lash”. By striving for a working principle that works without additional material (the metal clips) the designers of the unconventional stapler reached a solution with a substantially lower environmental impact (no metal clips while same lifetime as conventional product) and a higher use value in standard applications (no more “running-out-of-clips”) at the same time – they changed the technology.

Figure 3: A conventional stapler (left) and a stapler working without staples (right).

3.2 Fundamental versus incremental improvements

As pragmatic and achievable downward-oriented product optimisation is, it only leads to incremental improvements. However, fundamental (radical) improvements are needed to achieve Factor-4-to-20 increased resource efficiencies [7].

Unfortunately, we can see that traditionally the application of LCA within ecodesign (i.e. ecodesign based upon results of an LCA study) often leads to downward-oriented environmental improvements. This may be exemplified by relating to Brezet’s four-stage-model (see e.g. [8]): The model differentiates between:

- Eco-redesign
- Ecodesign
- Sustainable Product Innovation and
- Sustainable Society

… which may lead to improvements of about factor 2, 4, 10 and up to factor 20, respectively. However, both the state of implementation in industry [9] and the amount of known real-life examples indicate that the stage of sustainable product innovation has not yet been reached, let alone the stage of sustainable society.

It therefore seems paradoxical that from its original focus on a flexibly implementable Functional Unit (as defined in the activity of LCA), the ecodesign activity is very often limited to incremental redesign outcomes, which are – if at all based upon an LCA study – limited to the specific and detailed lower system levels, and not rising to the challenge of finding different representations of the Functional Unit established at the beginning of the LCA.

Instead of sub-optimising a particular, initial representation of the Functional Unit, ecodesign should thus rather seek super-optimisations, i.e. entirely different realisations of the given Functional Unit and in that way push forward innovative potentials, leading to overall environmental improvement at the same time.

4 THE PSS APPROACH: HOPE FOR HOLISM

Product/service-systems (PSS) is understood as a strategy focused on the provision of usage value of products through integrated solutions of products and services over an extended (for the company) product life period. An underlying principle behind a PSS strategy is to shift strategy from business based on the value of the *transfer of product ownership and responsibility*, to business based on the *value of utility* of the product and services. In many PSS cases the customer thus pays only for the use of the product when needed and does not have to worry about operation, maintenance or disposal. The meaning here is that the company can more freely decide to reuse, rationalise and enhance the products and services which they integrate in the PSS more efficiently throughout extended life phases. This strategy allows companies to enhance their competitiveness by expanding features, value and benefits not apparent with traditional product-oriented offerings [10].

An example for an implemented PSS is ‘RetailCare’, a system where the Danish company Danfoss issues a product offer to supermarket companies, that includes not only the installation, but also a continuous monitoring and optimisation of the customer’s refrigeration plants. Danfoss thereby works towards the following goals, (Figure 4):

- Improving the company’s position in the value chain
- Improving the visibility of their products’ virtues
- Optimal exploitation of the customers’ plants efficiency potential – thus yielding cost reductions for the customers

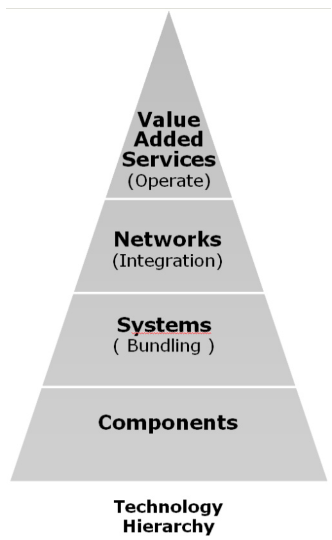

Figure 4: Upward-oriented technology hierarchy and value chain [11].

But what does this mean for design? In order to be able to design a PSS, one needs a broader overview of the product, its life cycle and the *stakeholder gallery* (i.e. the various types, roles and interests of all those involved at any stage of the product’s life cycle). Furthermore, working with PSS frames the product developer’s thinking in terms of systems, thus expanding the solution space in order to encourage creation of radically optimised solutions and avoiding focusing on sub-solutions. This should be achieved by a re-focusing of activities further up the value chain, meaning that the development activity must necessarily incorporate a slightly different set of profiles and competencies to be able to conceptualise a PSS.

In short, the PSS approach challenges the conventional artefact-fixated approach, in its transformation of business based on the sale of goods to business based on offering a combined product/service-system with continuous value provision to the customer.

5 CHALLENGES FOR PSS DEVELOPMENT

Despite the fact that PSS necessarily results in a much more complex, broad, whole-system frame, incorporating a broader set of 'building blocks' (products and services being conceptualised simultaneously, as opposed to just products), LCA is still capable of acting as measuring tool to compare different PSS solutions. This advantage of support by a fully established methodology can and should be exploited much more than today. We can see initial attempts at PSS methodologies [12] but believe that there is much work to be carried out in this area.

In order to make PSS strategies more comprehensible specific research is needed in fields such as

- Product & process design constraints: What design and manufacturing issues are relevant when designing a product/service-system? (Modular design? Design for disassembly? Refurbishing? Remanufacturing? …)
- Implementation constraints: What are the key factors that have to be taken into account in order to transform a classic single-product-based business to a PSS?
- Acceptance constraints: How to produce and successfully implement PSS solutions that replace conventional product-based solutions, with a necessary acceptance of the targeted user?
- Competence challenges: Who to invite around the table when conceptualising PSS solutions? The matter is much more complex than product development, integrating a greater spectrum of competencies.
- Investment challenges: How to convince company management to buy into PSS strategies, which essentially have the potential of changing the definition of core business for the company?
- and many others …

6 DISCUSSION

Our main point with this paper has been to highlight an opportunity for the established, but traditionally rather discipline-segregated sciences of LCA and ecodesign [9] to meet in a productive manner when considering PSS development. The opportunity to maintain a holistic, upward-directed focus for environmental improvements exists in the aims and methods connected to PSS development. There are surely a series of challenges connected to the development of methods, tools and the actual implementation of strategies for PSS, as all of these entail quite complex alliances at various levels of a typical company organisation, and across a broad range of subject disciplines.

7 THE SUSTAINABLE INNOVATIONS GROUP (SIG)

In recognition of the need to bring a closer relationship between the theories and practices of LCA, ecodesign, innovation and product development, the Sustainable Innovations Group (SIG) was established at The Technical University of Denmark, DTU, in 2005.

Our group comprises teachers, researchers and consultants in the field of sustainable innovation and it is our goal to reap the advantages of both the analytical and synthesis approaches to environmental improvement, and to set our work in the context of providing models and methods for the development of ecologically and economically sustainable solutions to students and to organisations.

Current project activities within SIG comprise Ph.D. students researching in design methodological aspects for product/service-system solutions and in aspects and constraints of implementing PSS in industry. Industrial partners comprise both manufacturers of electro-mechanical devices, public institutions and branch organisations – all interested in exploring options of PSS in their field of activity.

At the time of print of this paper we have educated two groups (about 120 students) of *Design & Innovation* engineering students at our university, in the theories and methods connected to product-life thinking, environmental analysis and PSS design and development. Furthermore, we have numerous bachelor and master-level projects in progress in this field. For the near future several concrete research and development projects are planed to be started.

8 SUMMARY

As this paper has exemplified, LCA is a capable tool for assisting product/service-system design, as it allows the assessment of products, services and combinations of these. Furthermore, LCA promotes thinking in systems and optimisations on higher system levels than can be found in traditional ecodesign approaches. In extending the notion of ecodesign, PSS encourages thinking at higher levels of systems, rather than at lower (e.g. component- and material-based) levels, and it promotes the combined and concurrent optimisation of physical products and related services.

It is our belief that thinking in and working with product/service-systems which has the potential to yield extreme improvements towards sustainability. As any product/service-system necessarily involves physical products, there are also material and manufacturing-related issues to be dealt with.

On the basis of this perspective, a dedicated group is working at DTU towards a better understanding of capabilities and further implementation of PSS in companies and academia. Working within the frames of PSS, the product developer should benefit from an expanded solution space within which to work, thus encouraging the creation of radically optimised solutions, and avoiding a focus on sub-solutions.

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